Recycler Status and Plans

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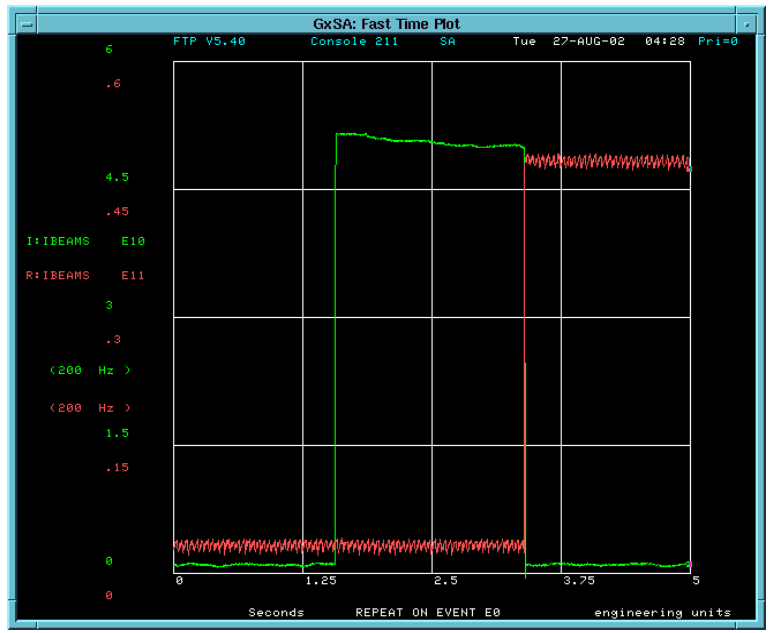
Director's Review 10/16/02

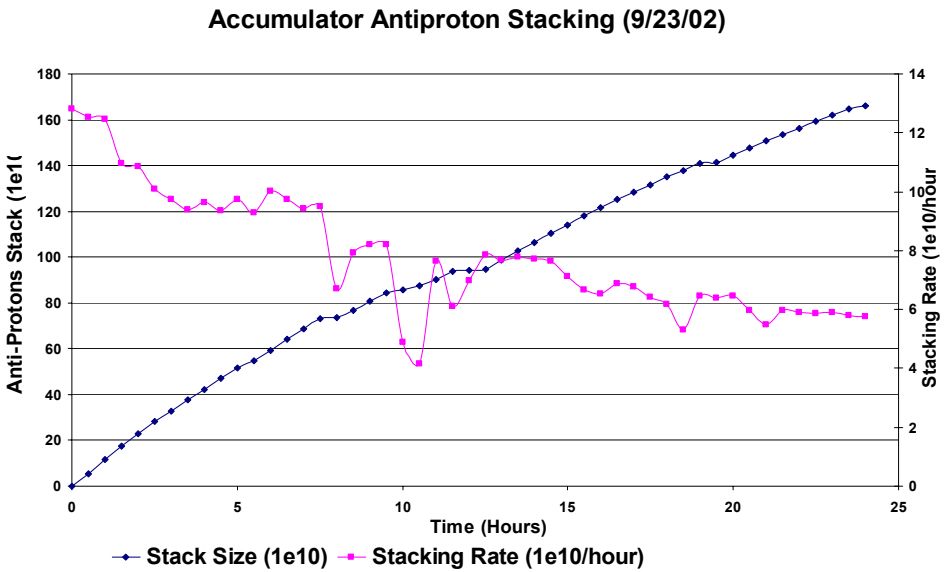


- Introduction to the Recycler Ring
- Recycler Improvements
- Present status and upgrade plans
- Summary

Introduction to the Recycler Ring

- The Recycler Ring is designed to store and cool antiprotons at 8.9 GeV/c. In the final configuration it will also Recycle antiproton from the Tevatron at the end of store.

- The Accumulator stacking rate decreases as the stack size in the Accumulator increases .



- An initial stacking rate of 12.4e10/hr has been achieved in the accumulator. (Sept. 24th 2002)

Introduction to the Recycler Ring…

- Transfer antiproton from Accumulator to Recycler will be done at small stack sizes, 30-40e10 to keep the stacking rate in the Accumulator high.
- Recycle antiprotons from the Tevatron at the end of the store (50-70% of pbars are left).
- The Main Injector Project was designed to support a peak luminosity of about 5-8e31 cm^{-2} sec^{-1} without the Recycler.
- The Recycler is designed to increase this luminosity "up to" 2e32 cm^{-2} sec^{-1}.
- Recycler lattice is made up of permanent combined function magnets. The FODO lattice is similar to Main Injector. We have added powered dipole, quadrupole and sextupole correctors.

Recycler Study and Upgrade Goals

	Goals
Number of stored antiprotons	*2e12 (5e12 Run IIb)*
Transfer efficiency(Acc→RR)	*>95%*
Stacking efficiency	*>90%*
Lifetime (2e12) (hrs)	*100(200-300)*
Equilibrium Normalized Emittance	*<10 pi mm-mr*
Emittance Growth rate	*~2 pi mm-mr*
Antiproton Recycling Efficiency	>50%*
Longitudinal Emittance	<54 eV-Sec

* This will depend on the emittance of beam at the end of store.

Recycler Upgrades (Since initial installation)

- Recycler End shim replacement
- Removal of magnetic heater tapes
- Alignment of beam pipes and BPMs
- Removal of high beta insert
- Realignment of All Recycler magnets with new fudicial.
- Install electromagnetic dipole correctors at each half cells, additional quadrupole and sextupoles.
- Install new magnetic shielding.
- Install new heater tapes inside each CFM and on beam pipes.
- Install new calibration circuit for all BPMs and calibrate every preamps.
- Install two scrapers and a new longitudinal Schottky detectors
- Install remote movable Stochastic cooling tanks
- Perform R&D on two vacuum sector by doubling Ion Pump.

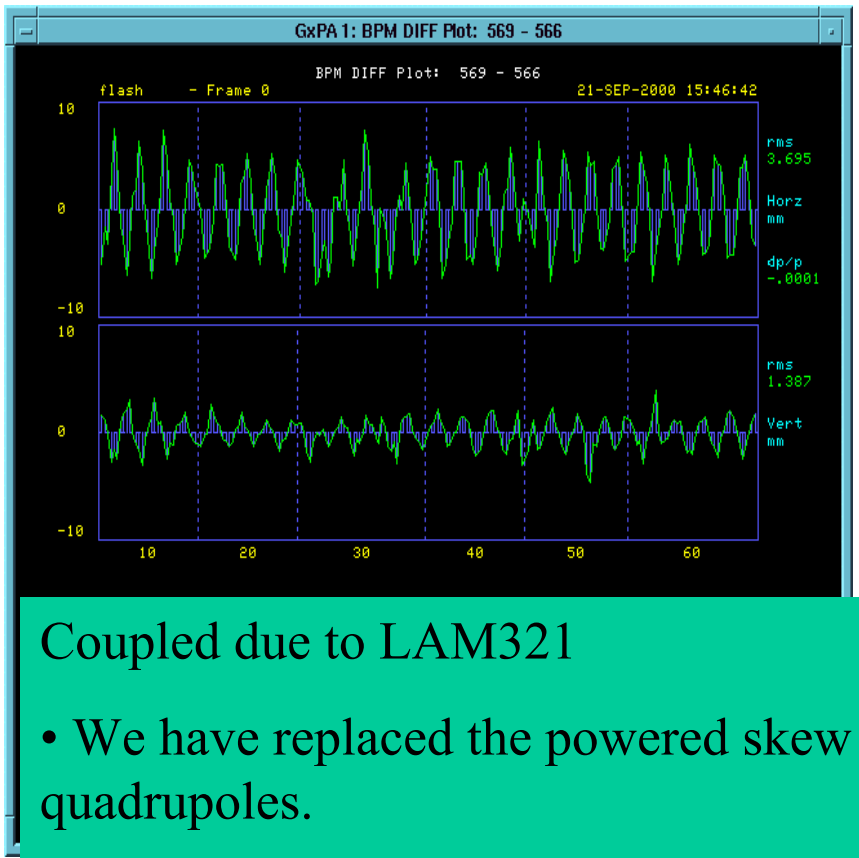
Recycler Studies

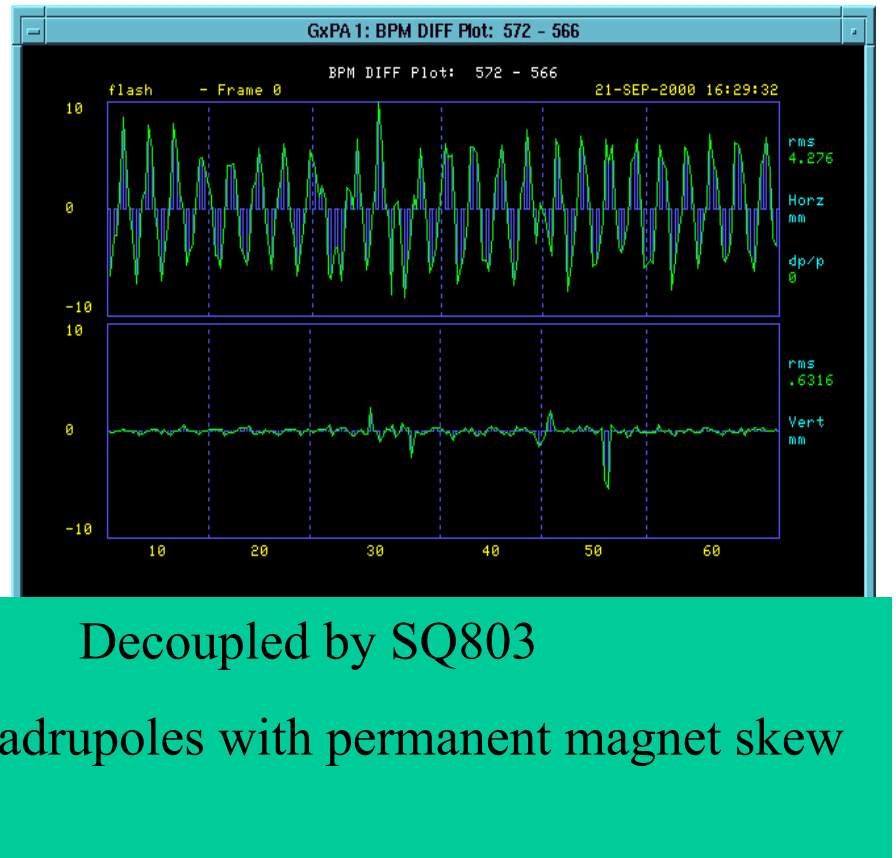
During last several months the Recycler studies have concentrated on the following topics

- Injection
  - Efficiency of protons and antiprotons
  - Emittance growth at injection
  - Aperture
- Recycler Lattice
- Beam Lifetime
- Antiproton transfer to the Recycler and stacking
- Commissioning of the cooling system
- Rf manipulation of beam
- Studies related with planed upgrades

Decoupling the Injection orbit

We installed two skew quadrupoles in the RR30 transfer line to cancel the effect of skew quadrupole measured in LAM321 and 328.



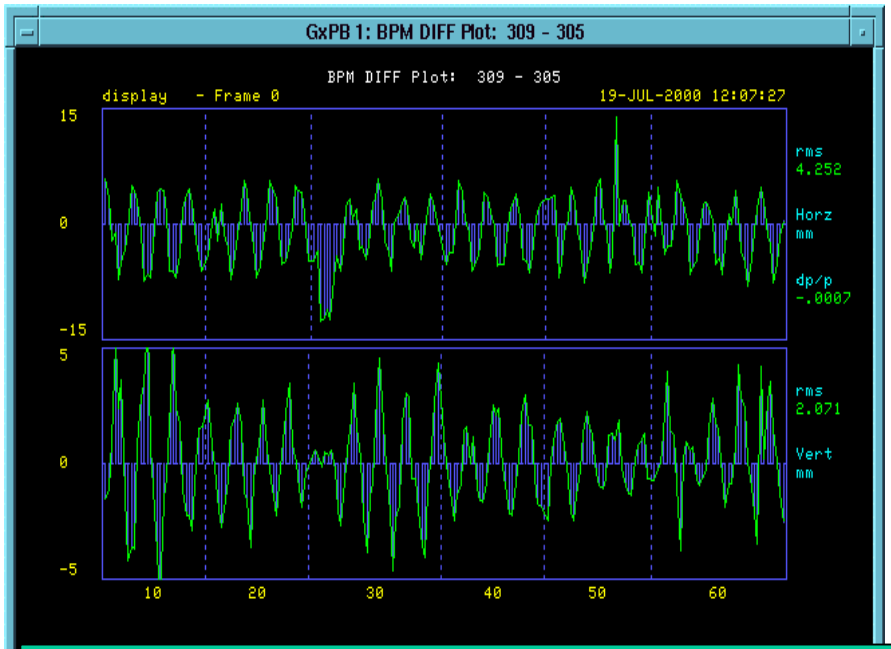


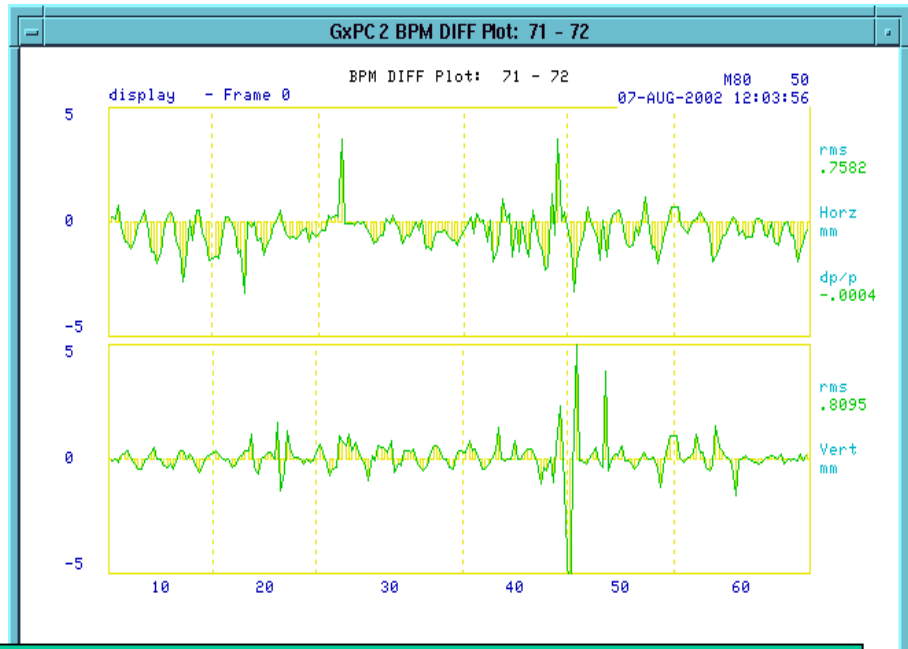
Coupled due to LAM321

Decoupled by SQ803

- We have replaced the powered skew quadrupoles with permanent magnet skew quadrupoles.
- At present we are using powered skew quadrupoles in the antiproton injection transfer line.

MI Magnetic Field effect on RR orbit





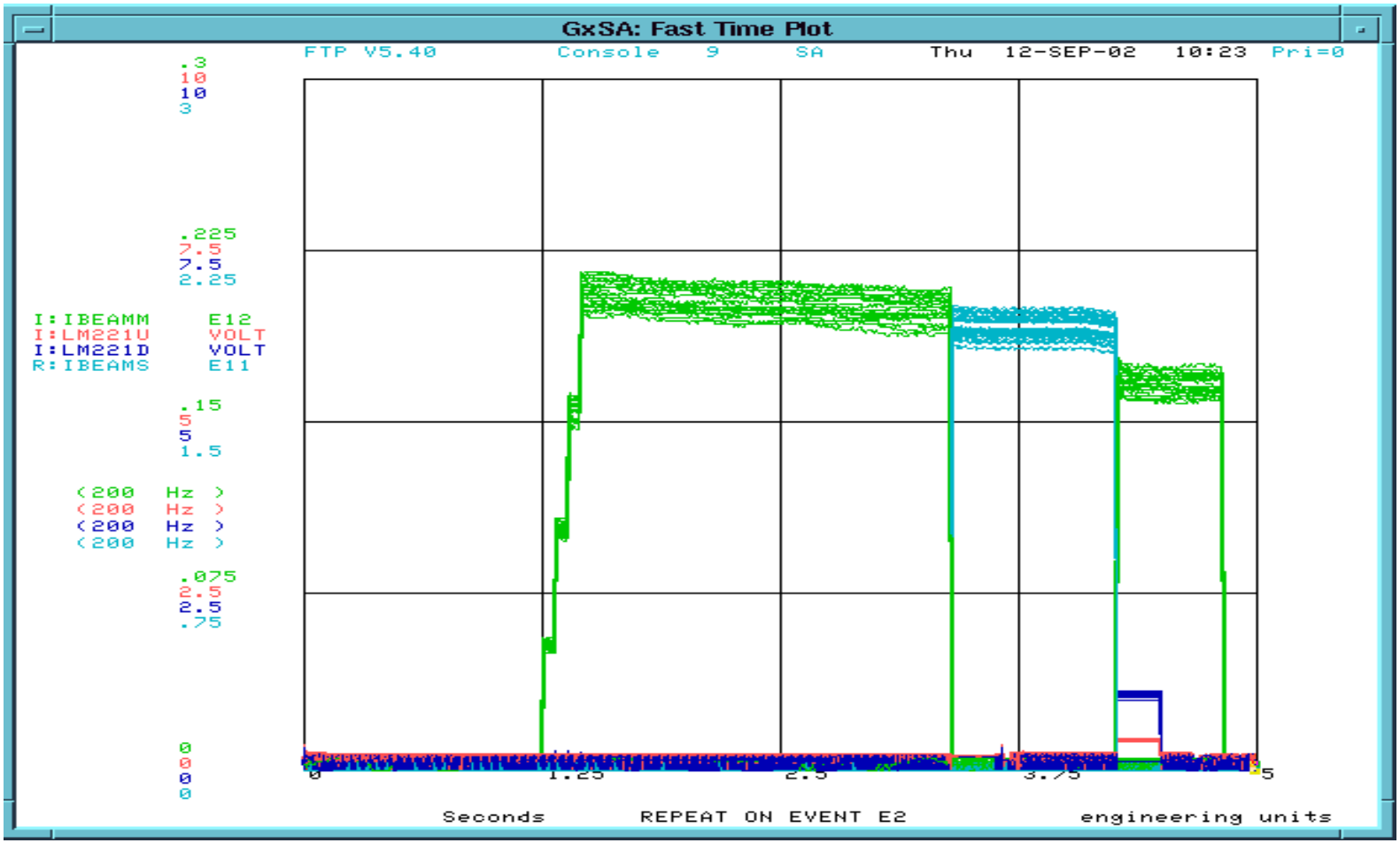
A R&D on shielding revealed that we needed new mu-metal and rapping technique. Old shielding was not very effective.

But the motion in dp/p and tune is causing longitudinal and small transverse emittance growth.This may require an active correction. We plan to add more shielding during next shutdown. We are also looking at feed-forward and feedback techniques.

Injection and Circulating lattice fixes

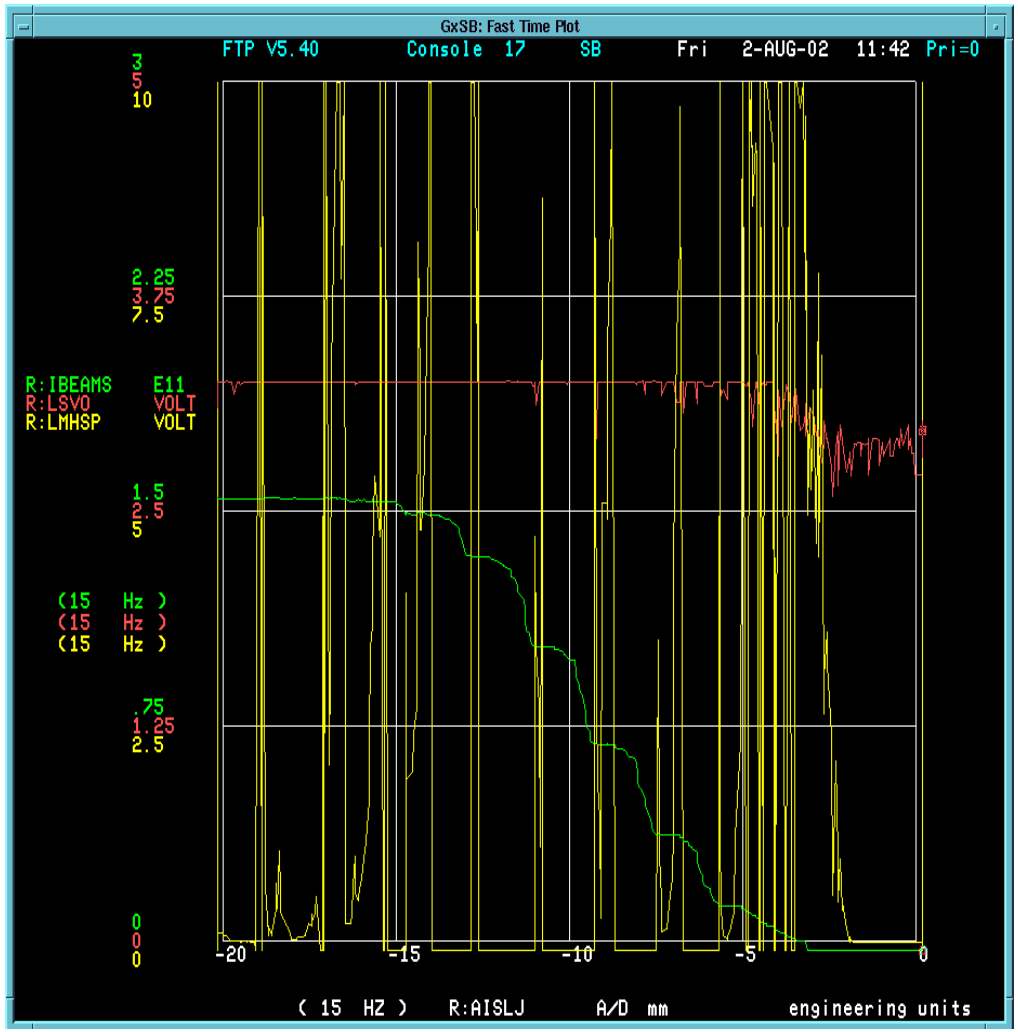
- In late Aug 02 we finished the installation of the feed down correction sextupoles at both injection and extraction locations.
- We have installed 4 (x & y planes) Multiwires in both the injection and extraction transfer lines.
- We have been successful in putting 53 MHz rf on to the Recycler rf cavities. Now we can inject 53 MHz beam into the Recycler, circulate and extract it in 53 MHz in the Main Injector. This allows to look at the extracted beam from the Recycler.
- Using IPM in the Main Injector, Recycler, Multiwires in both the transfer lines and 53 MHz beam capability we have been able to understand the injection much better.
- We are also working on Injection oscillation reduction.

Recycler efficiency



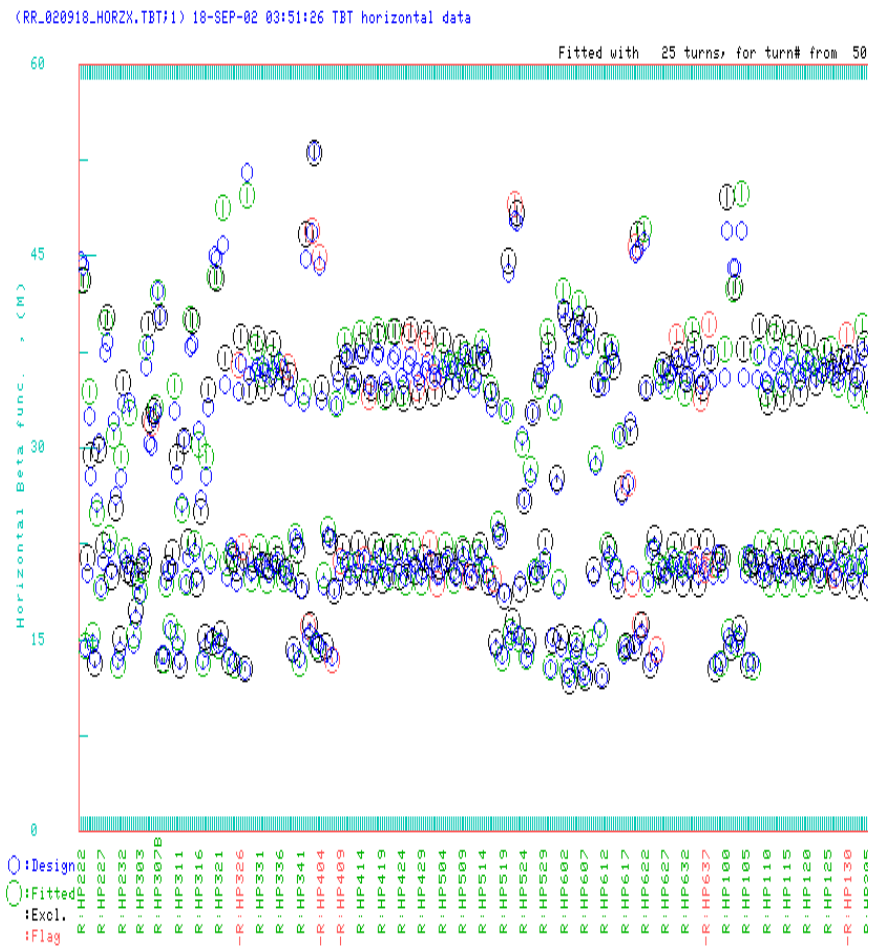
Loss at extraction is due to injection point loss and injection error.

Horizontal Aperture

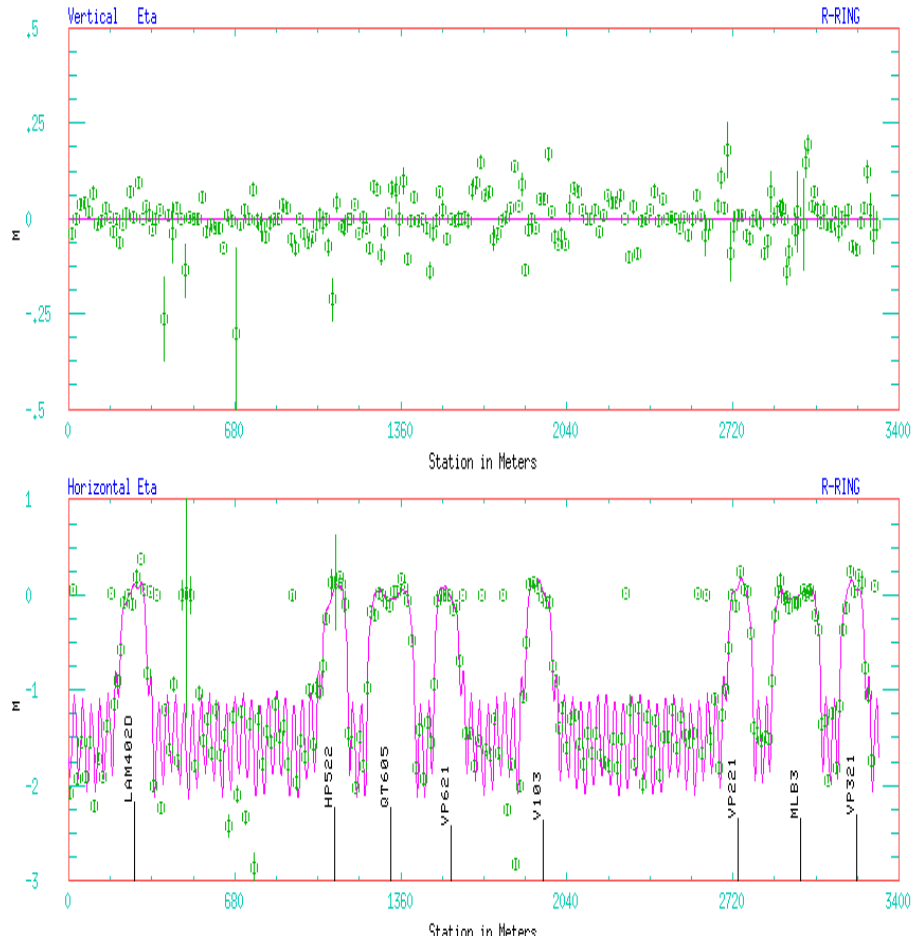


- After powering all the dipole corrector power supplies a new aperture scan was done.
- Installation of feed down sextupoles was done.
- We measured the horizontal aperture to be about 50 pi mm-mr.
- Vertical aperture is about 40 pi mm-mr.

RR Lattice functions

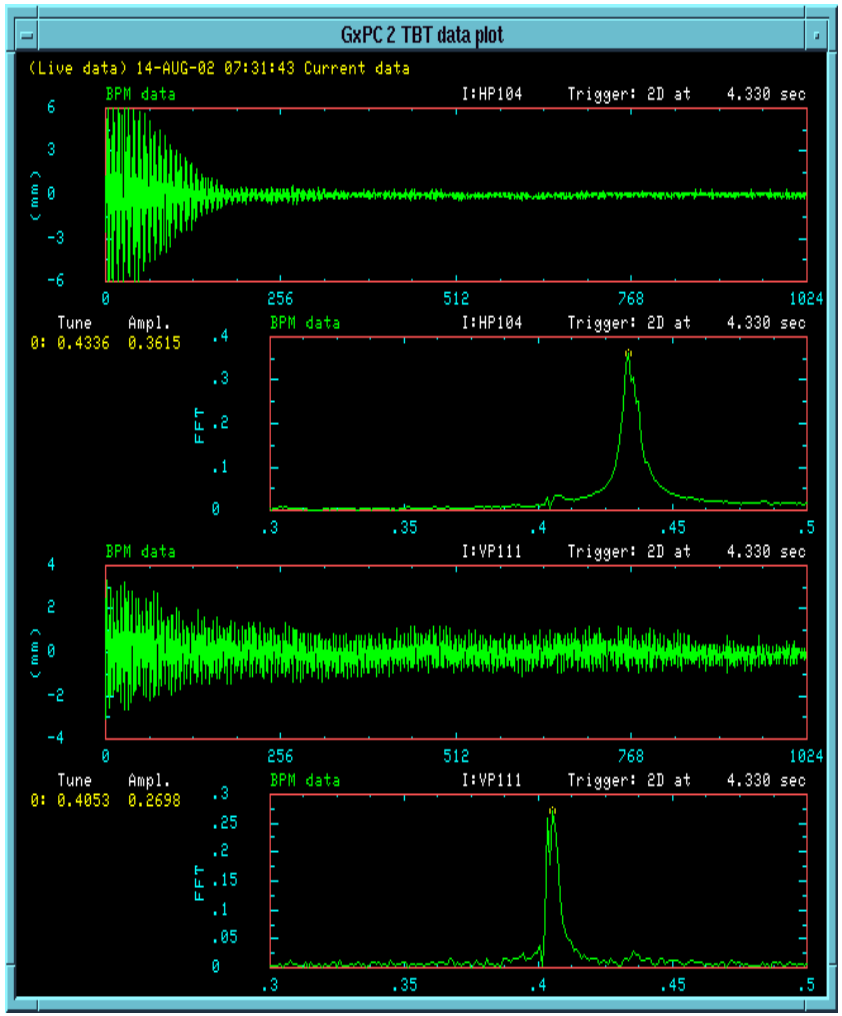


Horizontal Beta

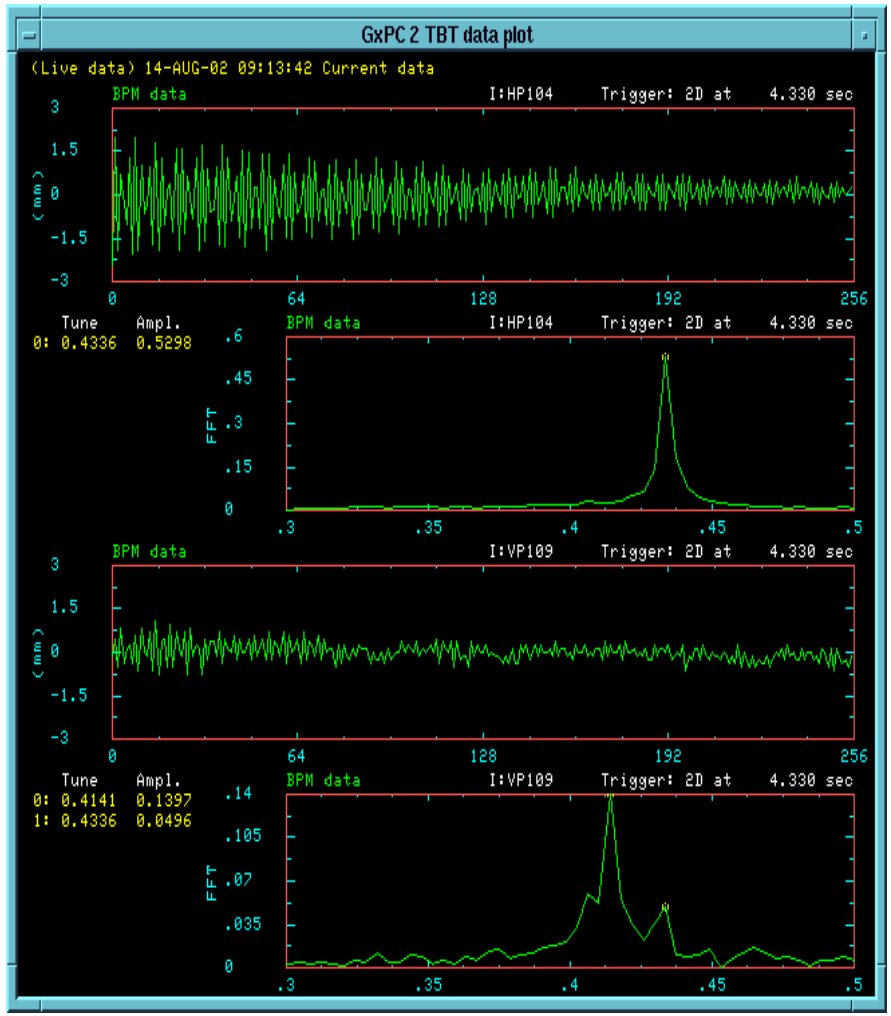


Recycler Dispersion

MI Reverse turn by turn

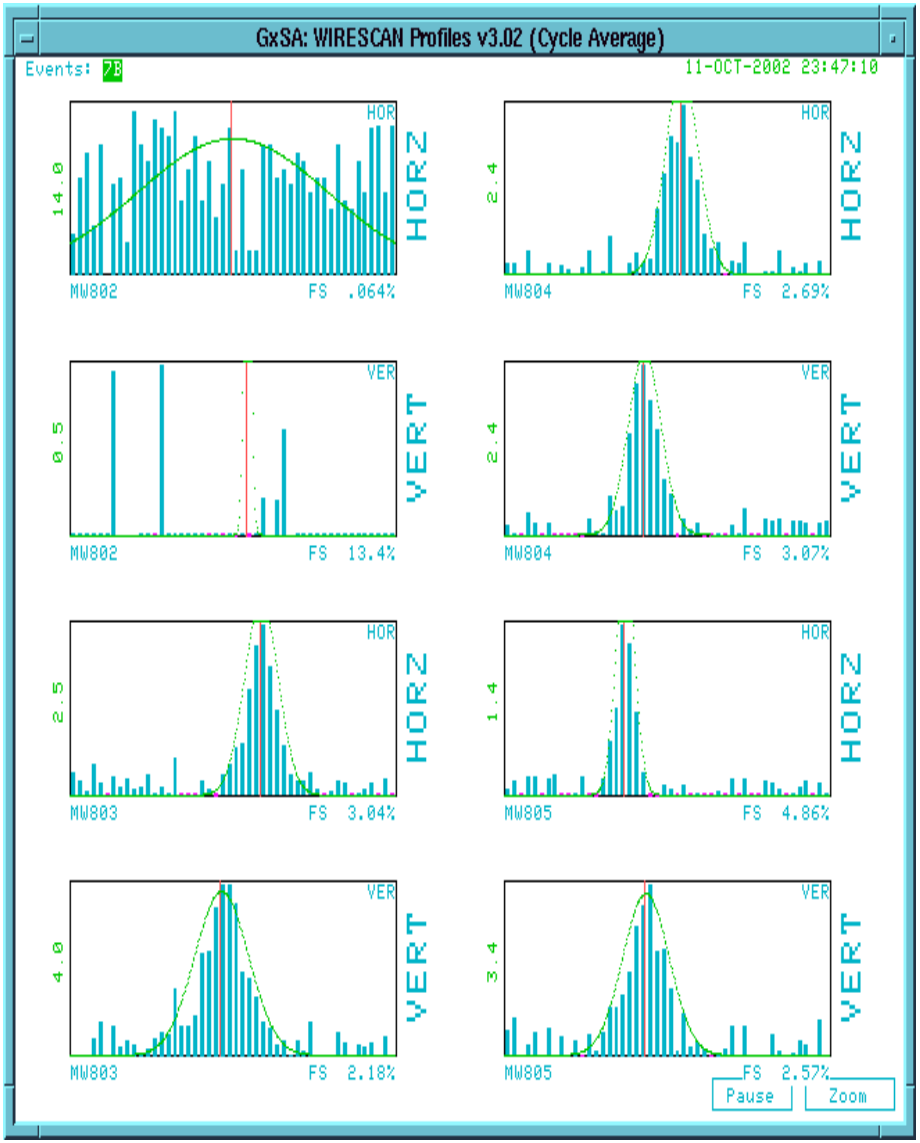


Before tuning.



After tuning.

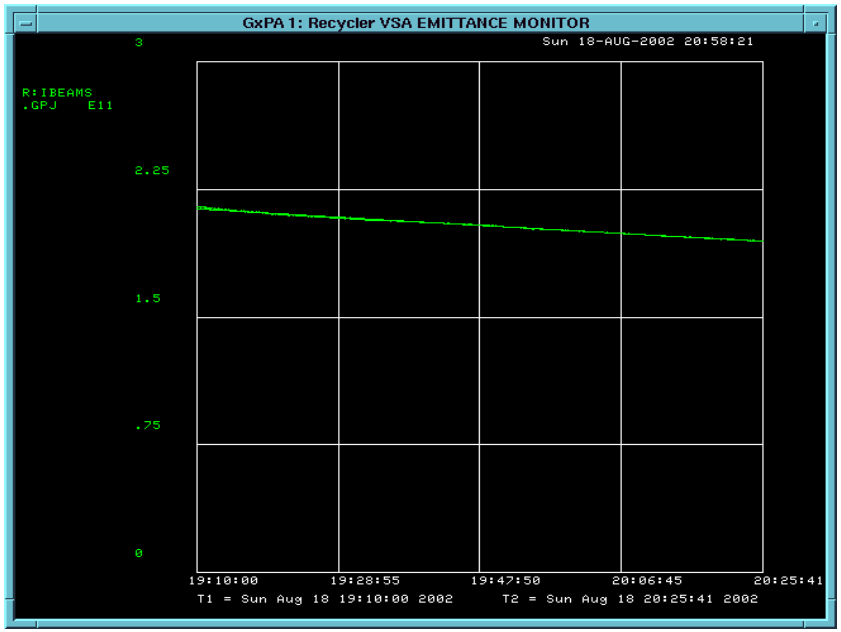
Transfer line Multiwires



Multiwires were installed in both the Recycler transfer lines.

These are used to match the injection, study coupling and tune the line in general.

Recycler Proton Lifetime



•Unscraped proton beam lifetime 13 hours with Main Injector ramping.

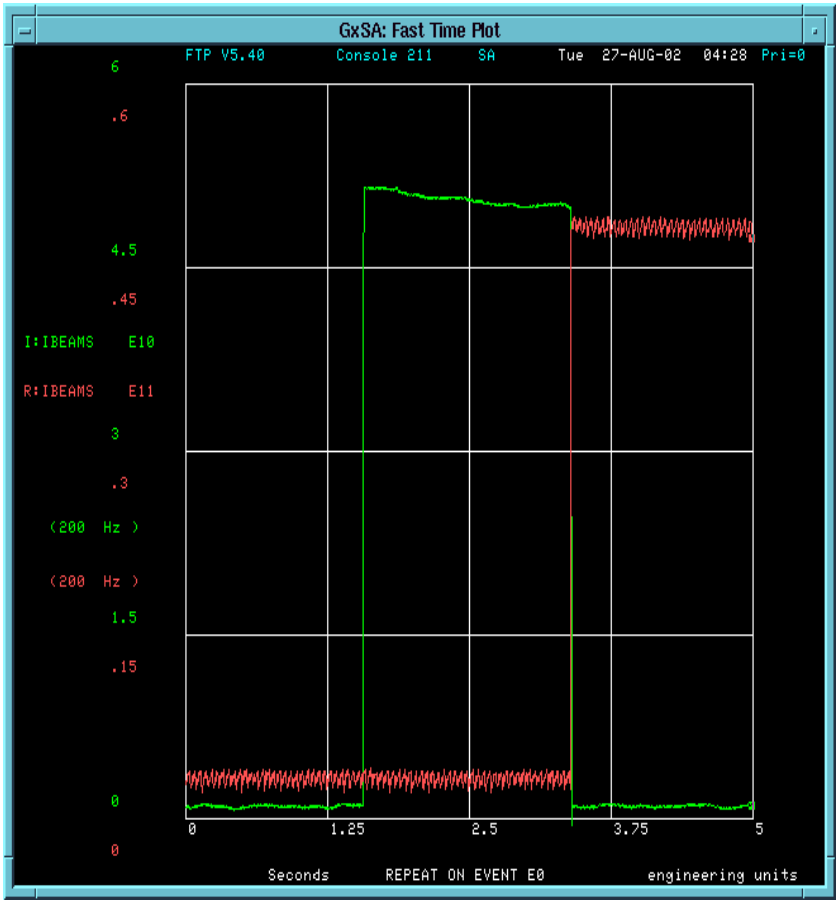
• The aperture does not fill for 2 to 3 hours with Main Injector ramp.

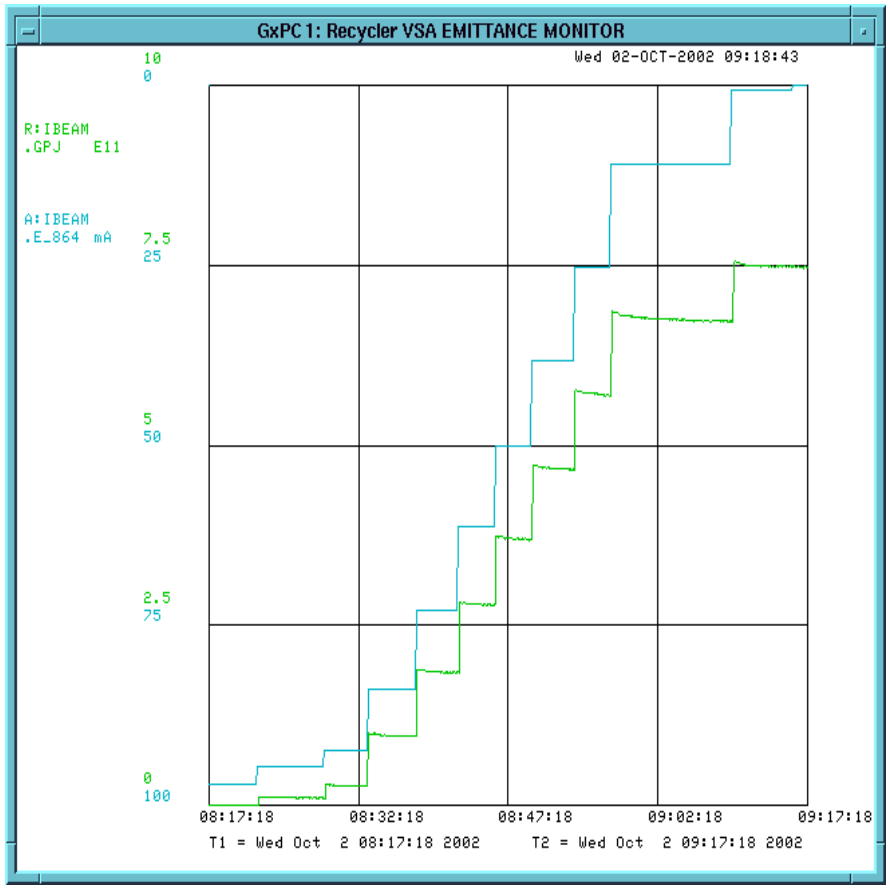
• This is considerable improvement as compared to less than a minute aperture filling

• After we installed all the sextupole feed down correction (Aug 02)

• After complete after scan in both H and V planes and centering the beam in aperture.

Antiproton transfer to Recycler

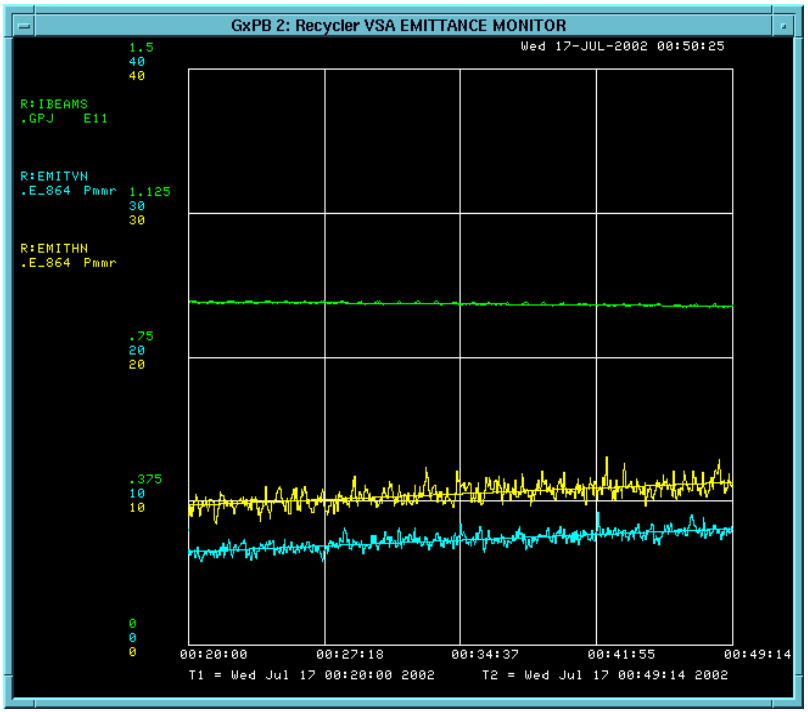


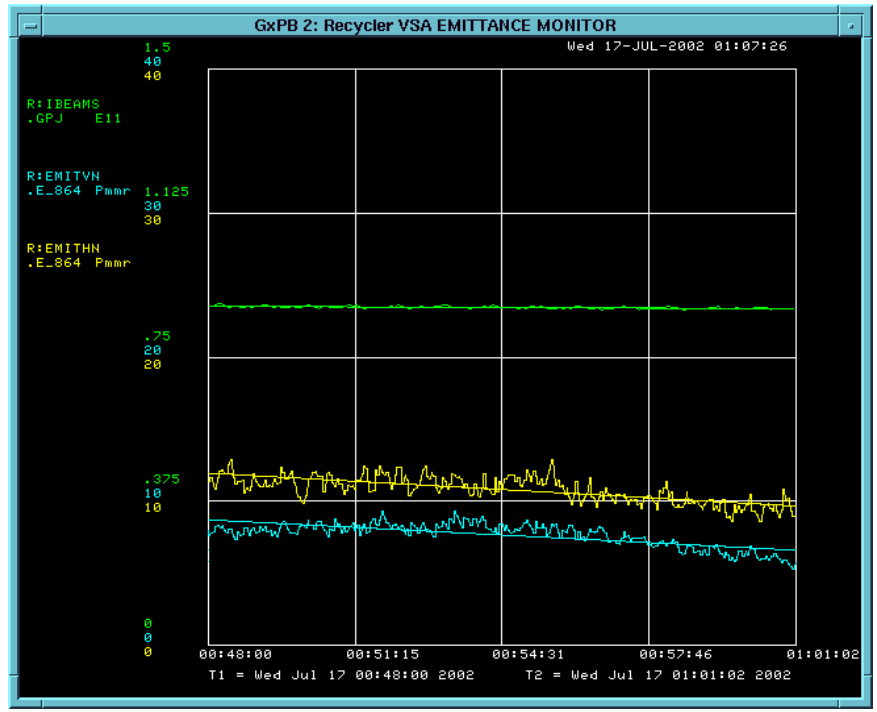


>95% circulating efficiency for 1st injection.

>75% stacking efficiency.

Pbar Heating and Cooling Rate





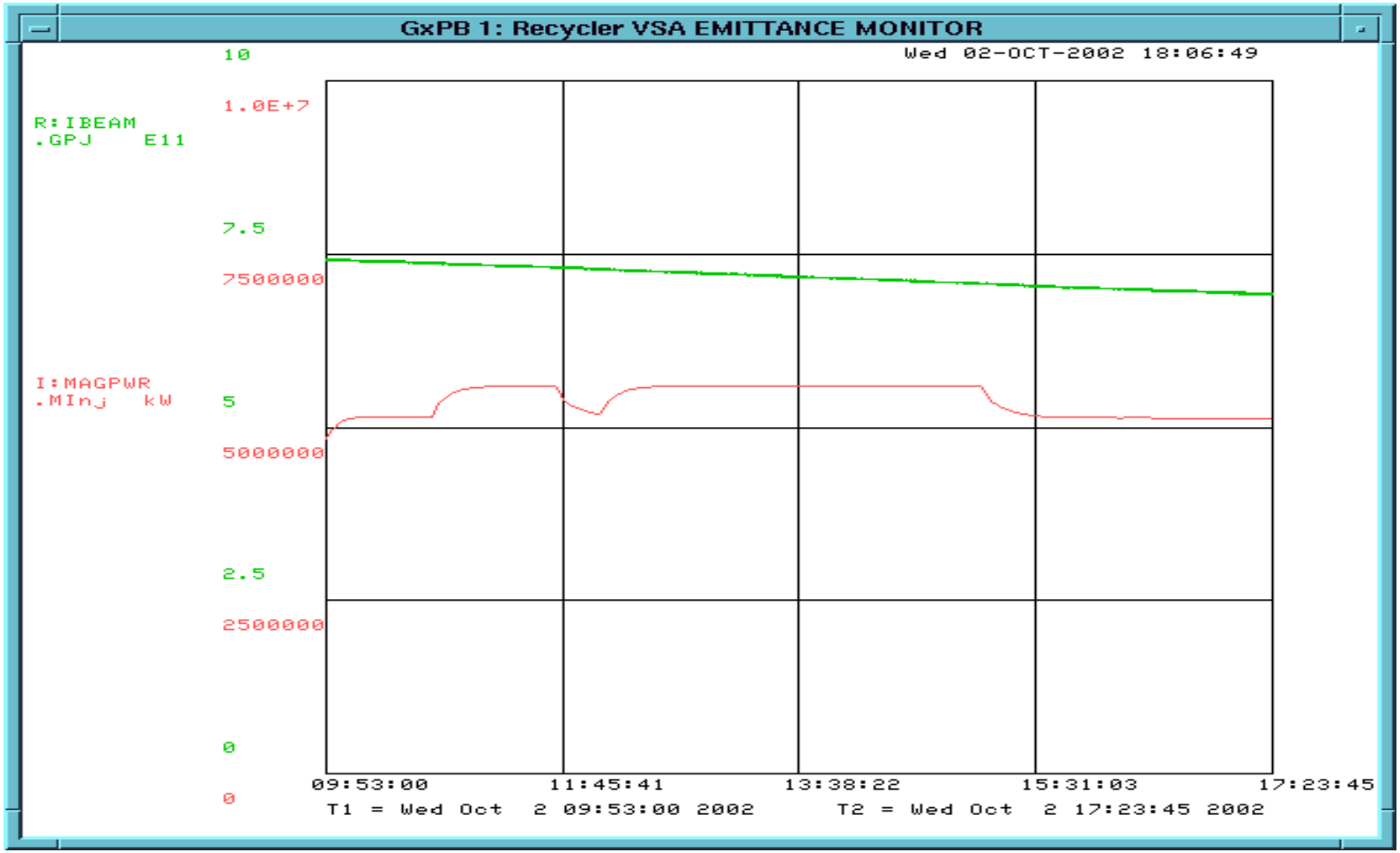
•pbar heating rate measured at this intensity is about 3-4 pi mm-mr/hour.

• This growth rate is similar to proton heating rate and is consistent with vacuum related growth (x2).

The cooling rate is about 10 pi mm-mr/hour. This is not a fully optimized system.

1e11 pbar in stack.

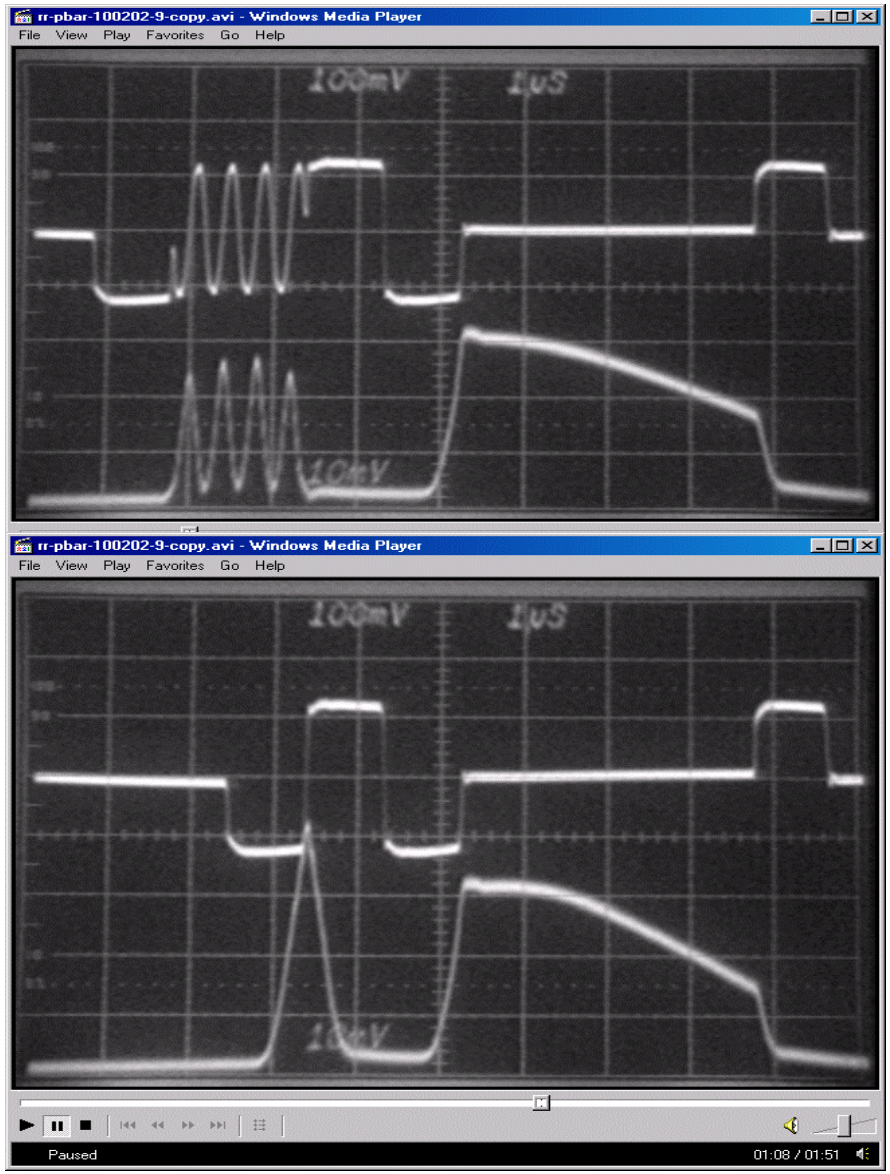
Pbar lifetime

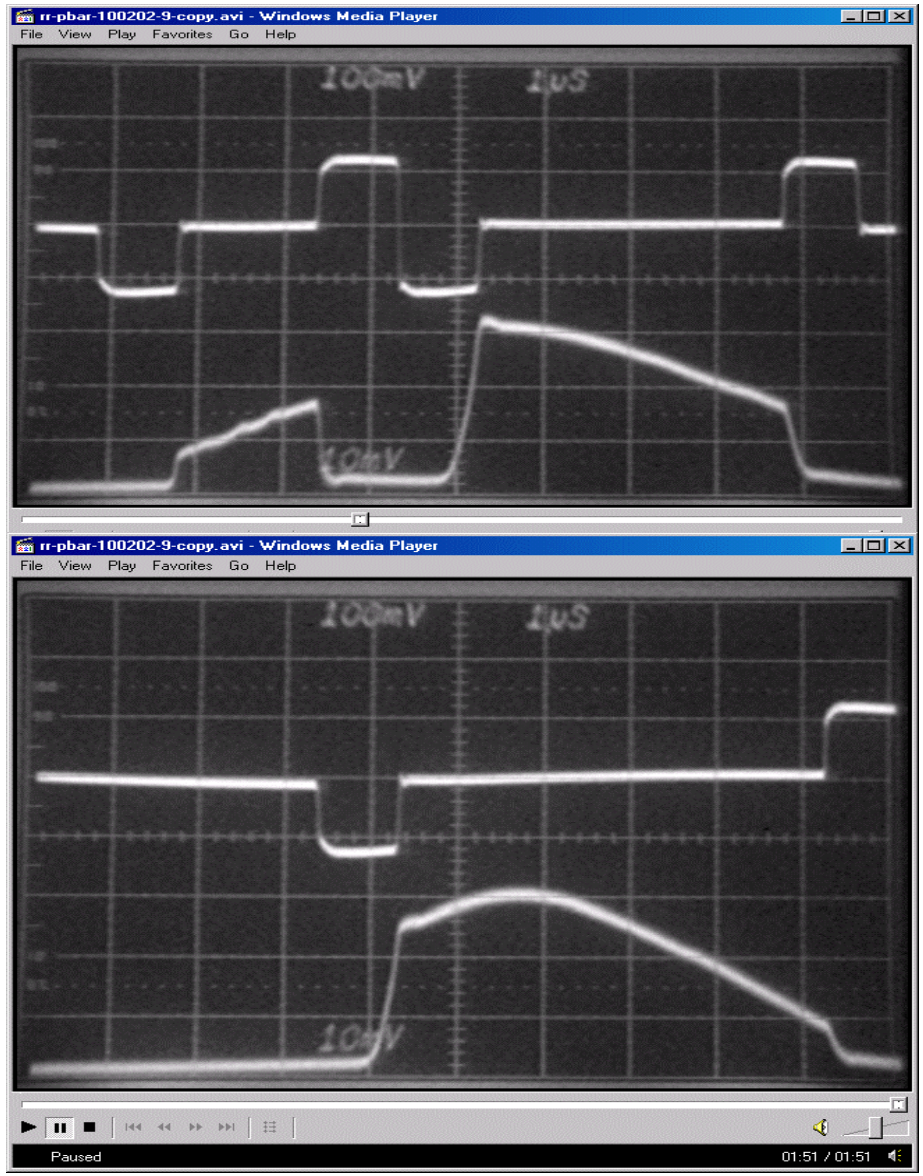


7 hours of store, 105 hours of lifetime for 0.75e12 antiproton.

(Cooling system was partially operational and tuning continues)

Antiproton Stacking RF manipulations

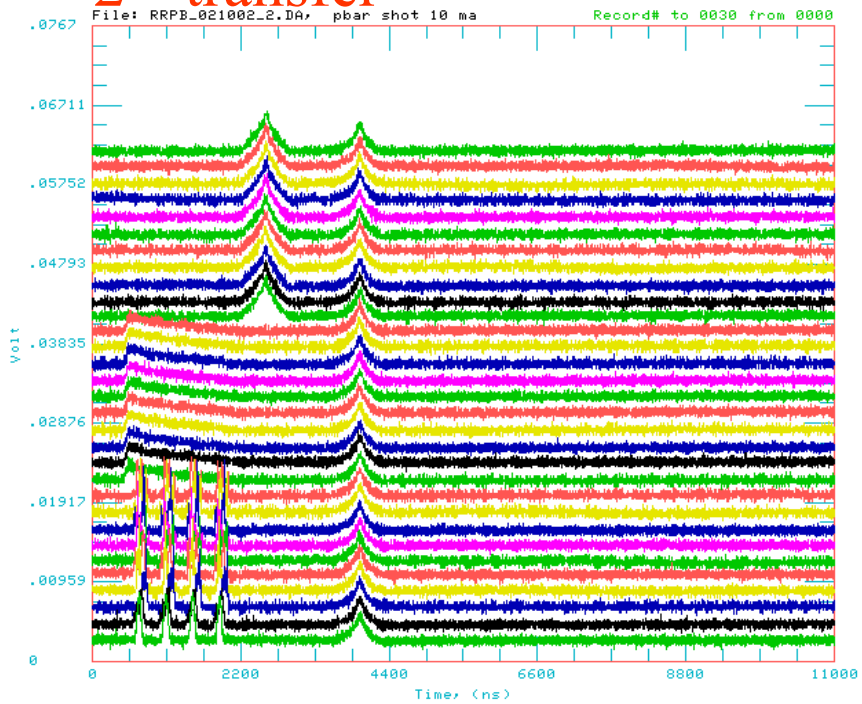




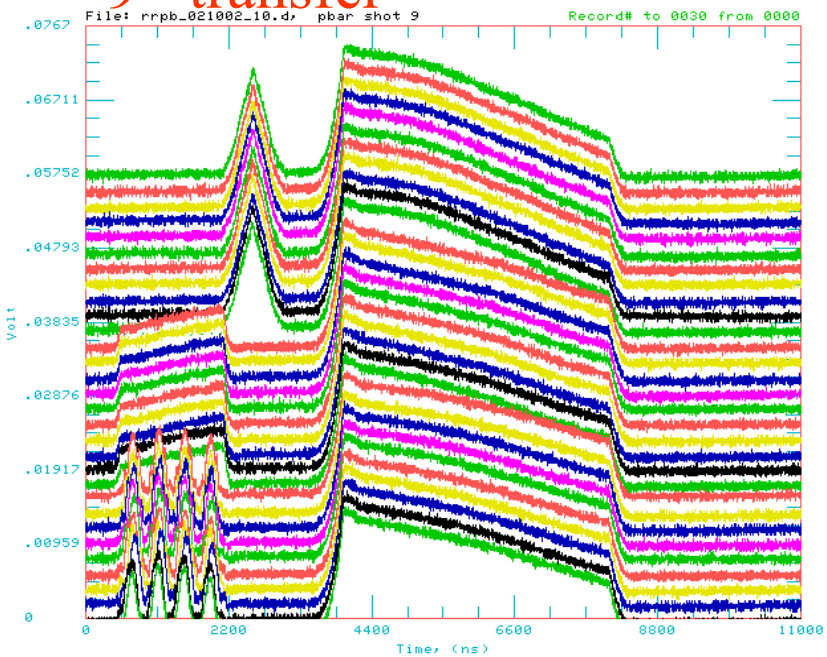
Insignificant amount of beam is leaking from the barrier buckets.

Antiproton longitudinal profile

2nd transfer



9th transfer

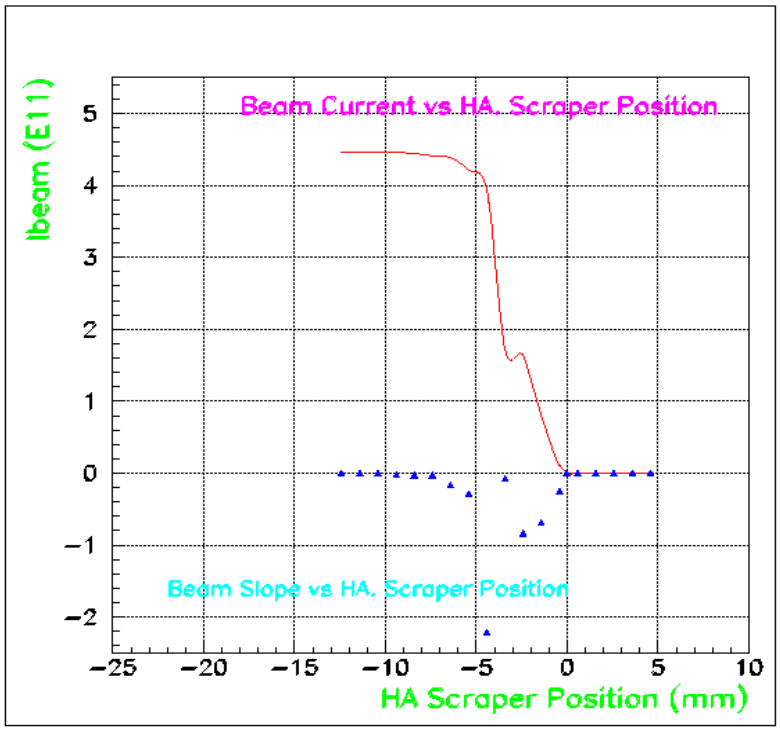


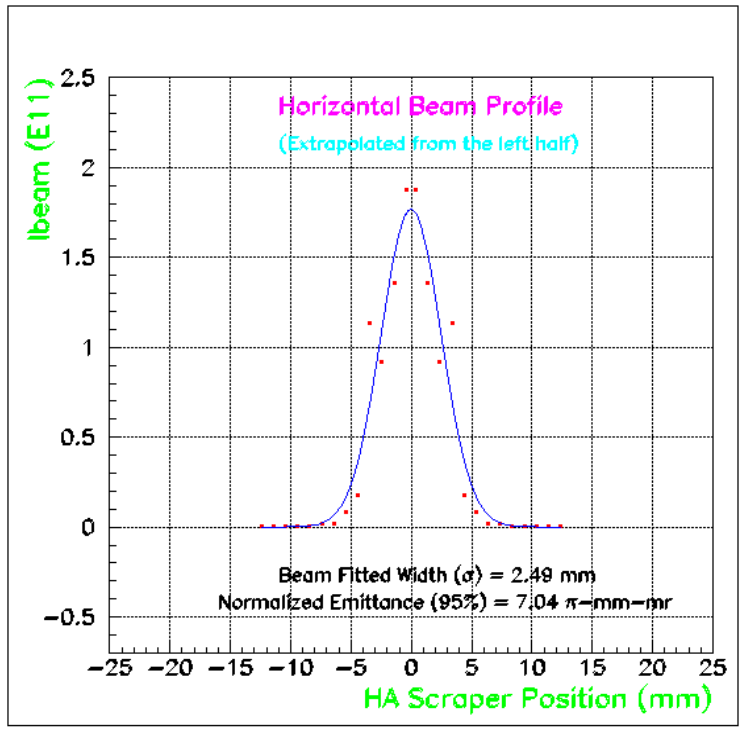
1. Bunches at injection in 2.5 MHz buckets had about 2eVs/bunch(20%)

2. Bunch after squeeze before adding it to main stack is ~9.5 eVs (20%)

3. The beam in stack is ~ 65 eV-sec (large error). There is a slope in the base which was not taken into account in this calculation.

Emittance of the Cooled antiprotons



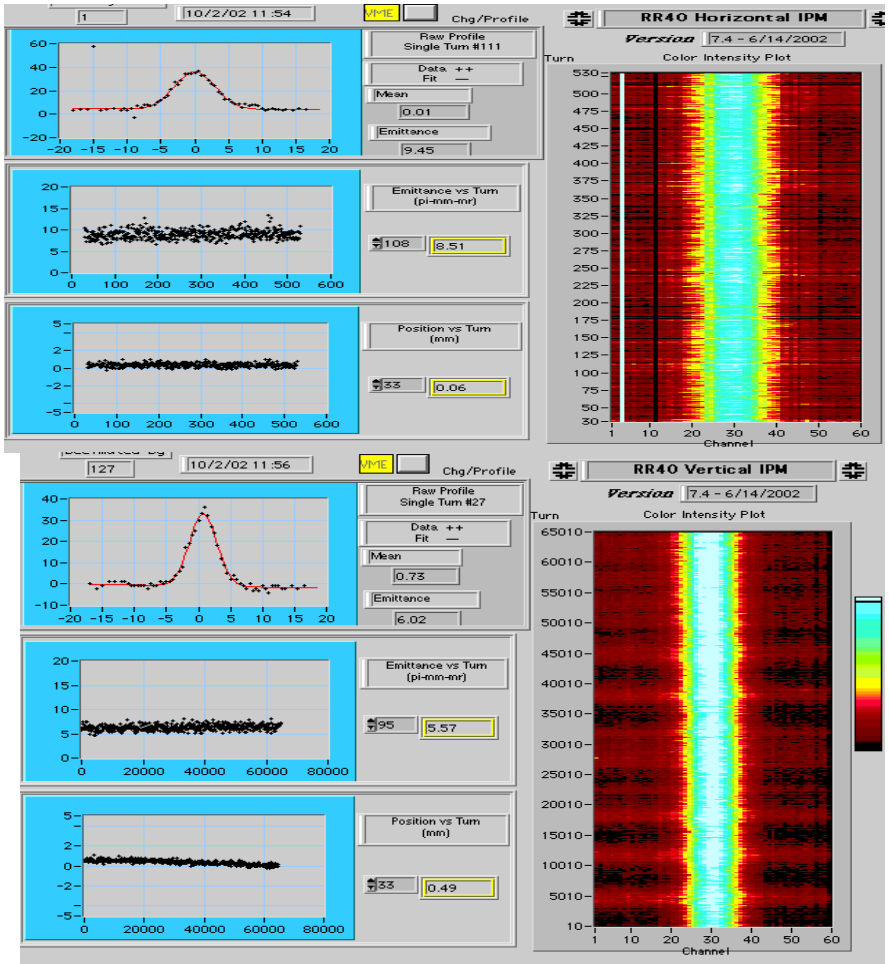


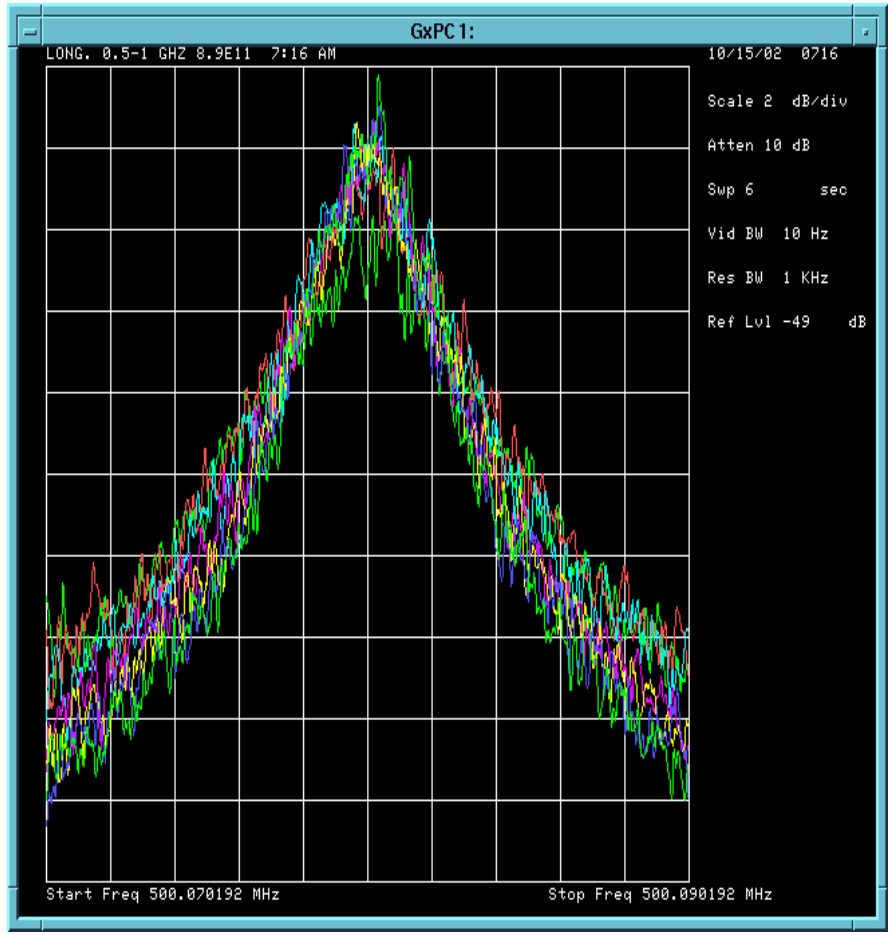
Measured emittance is about 7 pi mm-mr.

This scraping measurement was done with the Main Injector ramping and just after we had disturbed the cooled beam. We believe that the beam is smaller than the measurement indicates.

This measurement will be repeated with more calibrated instrumentation.

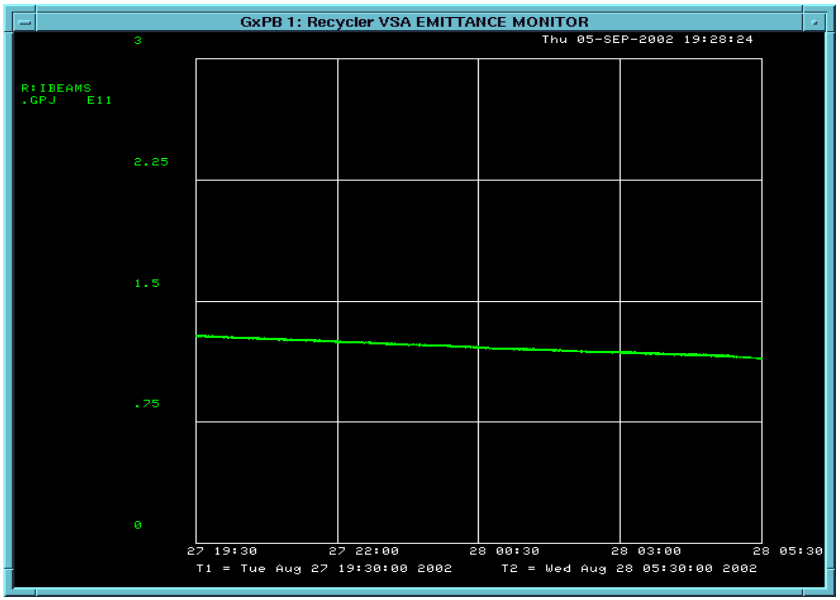
Emittance of the Cooled antiprotons

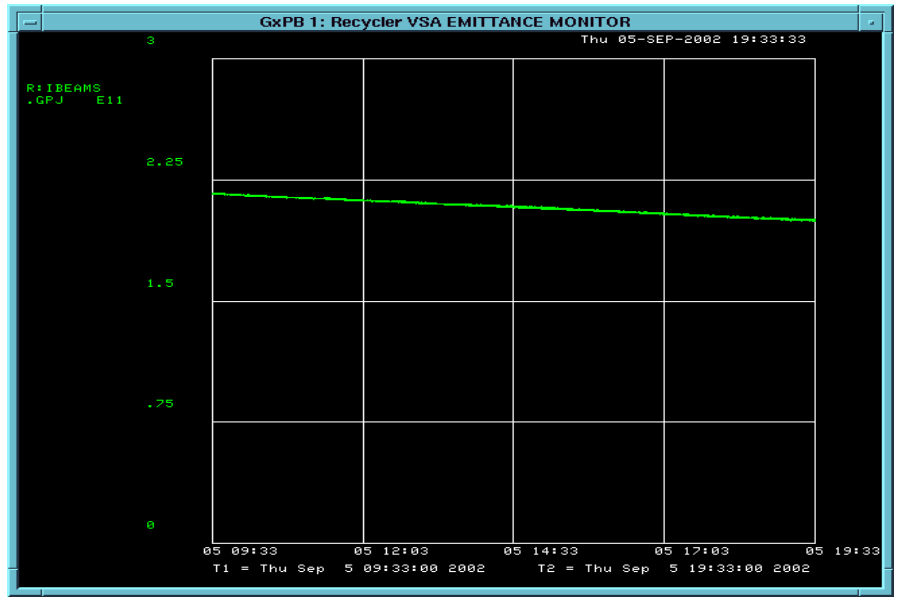


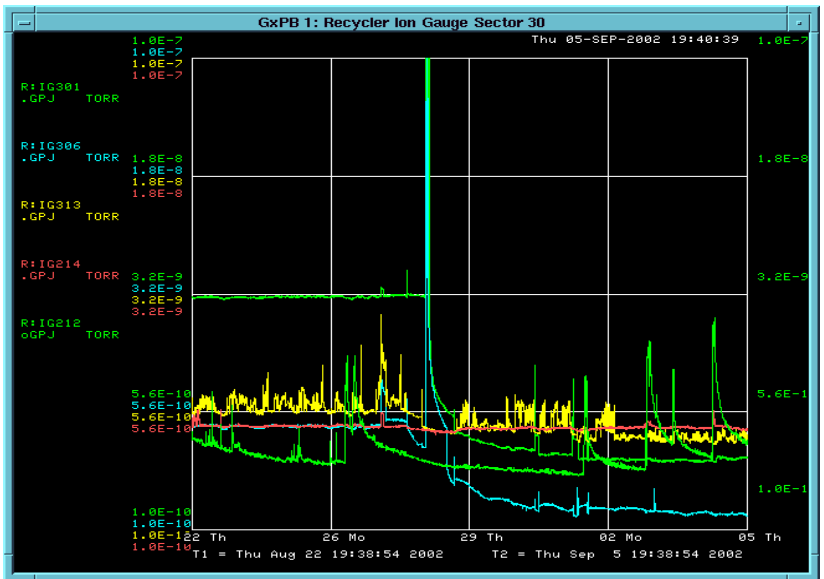


- Transverse Emittance is about 4-5 pi mm-mr at a stack of 75e10 pbar. IPM needs calibration. It measurement is larger than size measured by scraping the beam.

Effect of vacuum on pbar lifetime



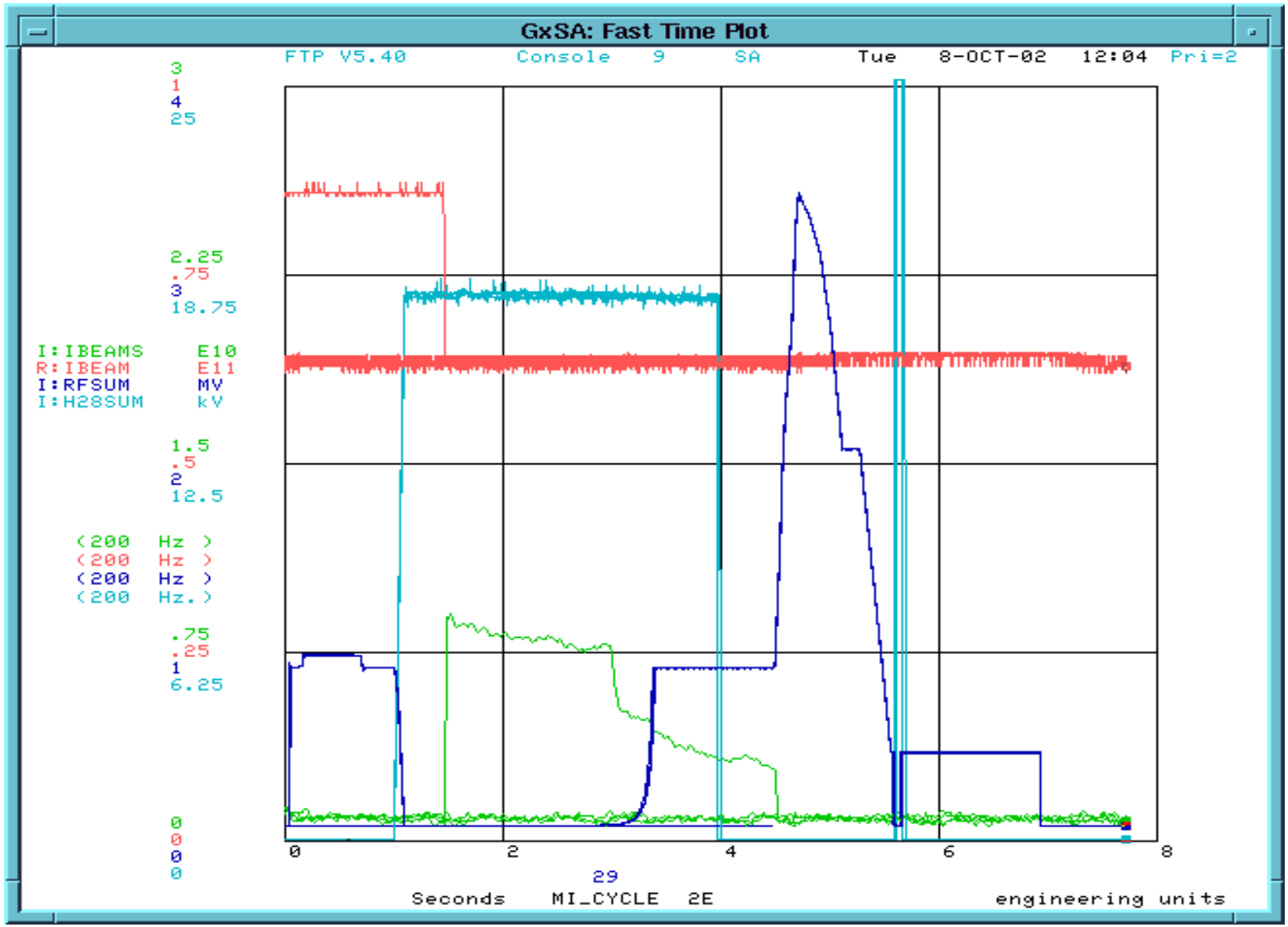




Lifetime improved from 90 hours to 125 hours after improving the MI30 sector vacuum by firing TSP.

Proposed vacuum upgrade will improve this considerably.

Extraction of pbar from Recycler



Recycler Progress

- In last two years we have made a significant progress in the Recycler performance and its understanding.
- Recycler lifetime has improved from a few mins to > 10 hours without cooling for protons.
- Recycler efficiency has improved from 25% to >90%
- Injection emittance growth is smaller. Beam is not filling the aperture at injection.
- The Stochastic cooling system has been commissioned with pbar. We have measured a cooling rate of 10 pi mm-mr/hour. When the heating rate is about 4 pi mm-mr/hour.
- A pbar lifetime of >100 hours has been observed for 75e10 pbar.

Physics Issue

- Injection and circulating Efficiency for proton and pbar is about 90%
- Emittance growth is about a factor of 2-4 larger than the design. Significant fraction of this appears to be vacuum related.
- Recycler performance is adversely affected by the Main Injector ramp.
- Circulating and injection lattice and aperture
- Operating point of the Recycler is sensitive to the Recycler orbit.
- Cooling needs further study and optimization.
- RF manipulations need further study and optimization.

Recycler Status

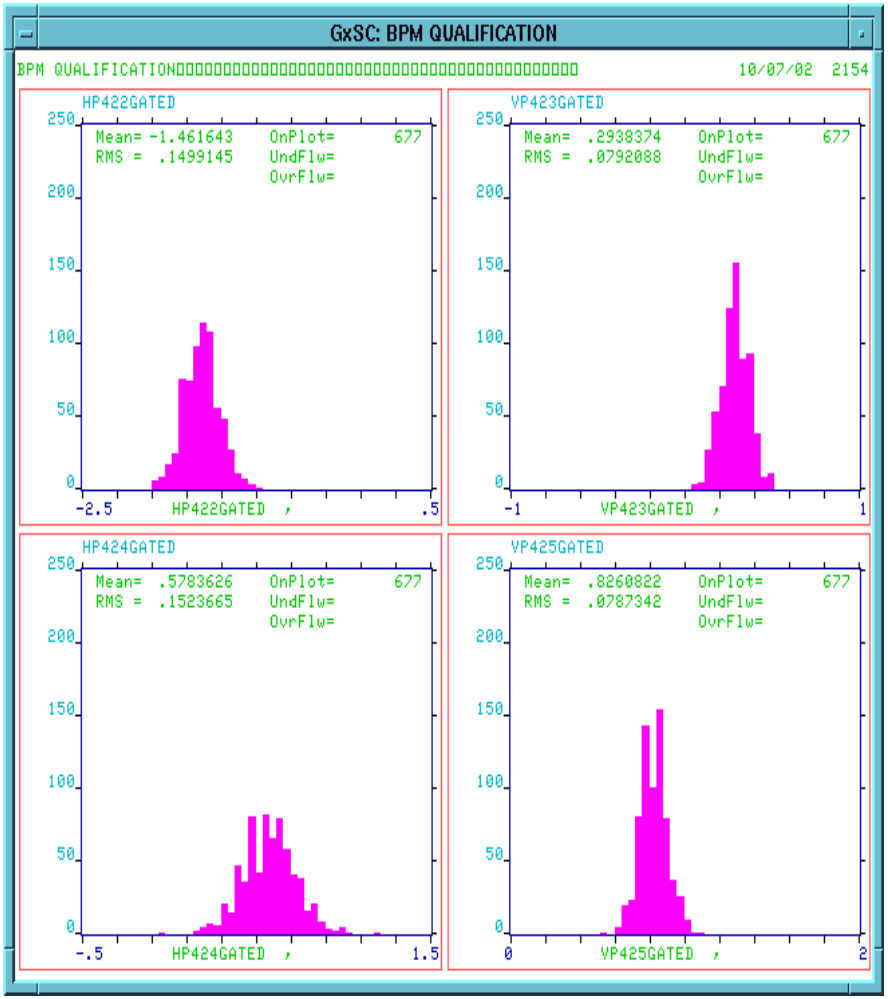
	Integration Goal	Achieved
Number of stored antiprotons	*2e12*	*0.75e12*
Transfer efficiency(Acc→RR)	*>90%*	*83%*
Stacking efficiency	*>85%*	*75%*
Lifetime (2e12) (hrs)	*100*	*105* (0.7e12)*
Equilibrium Normalized Emittance *pi mm-mr*	*<10*	*~7* (0.5e12)*
Emittance Growth pi mm-mr/hr	<2	~ 5
Longitudinal Emittance (eV-Sec)	<54	75

* The Stochastic cooling system is being tuned and new hardware are being installed. This performance is expected to improve.

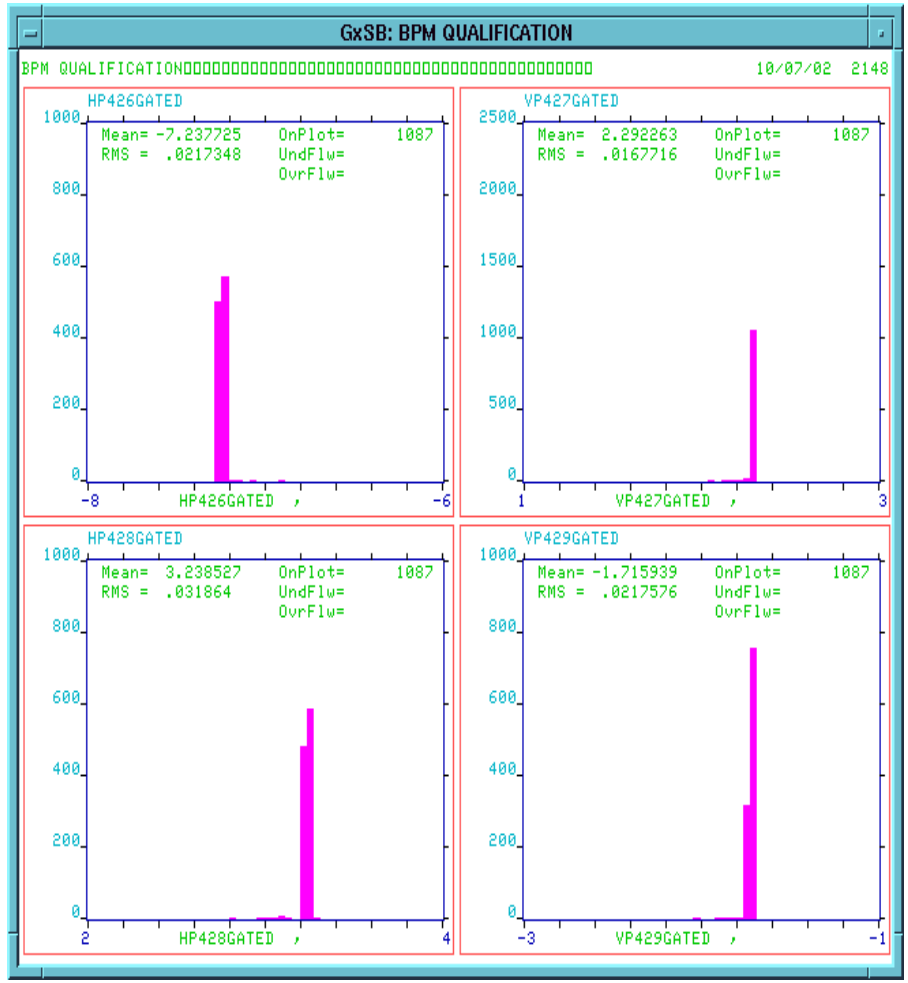
Technical Issues

- Instrumentation Upgrades
  - Beam Position Monitor
  - Beam Line Tuner
  - Flying Wire
  - Ion Profile Monitor (Physics Understanding)
  - Schottky Detectors
  - Injection Damper
  - Reliable, calibrated and operational Instrumentation
  - RF power and manipulations

Recycler BPM R&D



Present BPM's with resonant preamps and log amps, sigma = 0.15 mm



Test BPM's with modified preamps and digital receivers, sigma = 0.025 mm

Technical Issues…

- We need to develop several software to support new hardware being placed in the Ring.
- We also need to develop several software for operation and physics analysis.
- Accumulator to Recycler transfer
  - We need to measure the central momentum for the Recycler.
  - We need to redefine the 8.9 GeV/c for the complex.
  - We are proposing that all transfer takes place in 2.5 MHz.
  - We need a procedure which uses MI as a transfer line.

Mechanical Upgrades of the Recycler

- Vacuum upgrades
  - Double ion pump in the Recycler
  - Install insulator inside the CFM for higher temperature bake.
  - Bake at a higher (>110 deg C) temperature for 4 days.
  - Install more gauges and RGA
  - Find and eliminate small leaks
- Lattice Upgrade of the Recycler
  - Remove stuck old magnetic heater tapes from 24 magnets
  - Remove windows and use differential pumping
  - Additional correctors
  - Additional Magnetic shielding at select locations

Vacuum Upgrade Simulation

Simulation of the Recycler vacuum system and its upgrade is being done by a detailed model of the Recycler vacuum and a test stand setup.

Physics Process	Present Recycler Lifetime (hr)	Upgraded Recycler Lifetime (hr)
Single Coulomb	134	300
Inelastic Scattering	271	556
Multiple Coulomb	17	36
Nuclear Scattering	658	1340
Total Lifetime	14	30

Recycler Integration

We have started working on the integration of the Recycler into the Accelerator complex.

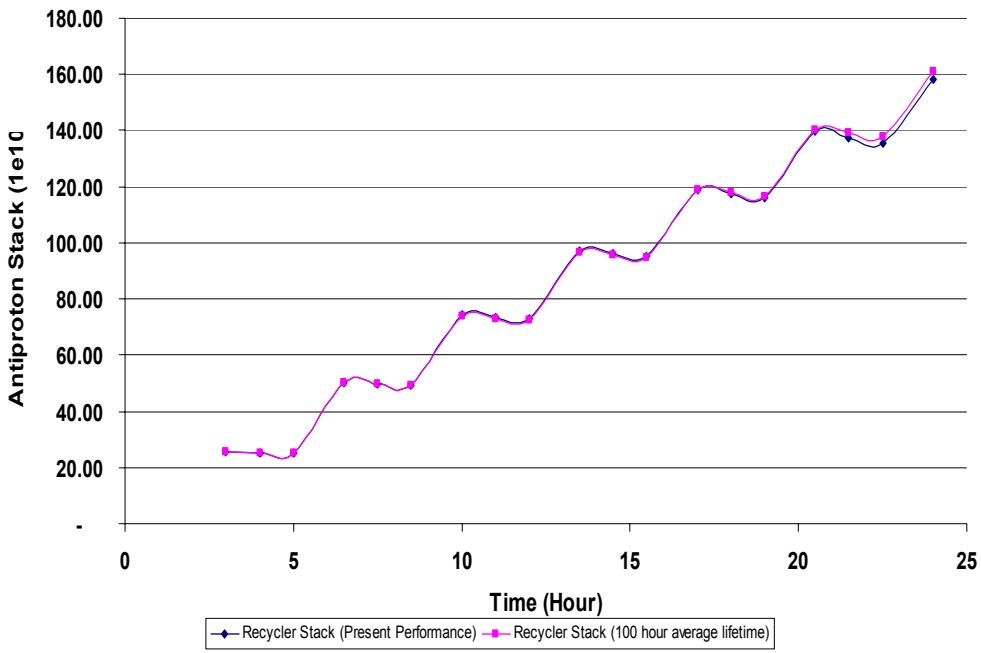
- Stack efficiently, reasonable lifetime and emittances.
- Re-bunch cooled beam in 2.5 MHz, transfer to MI and accelerate in MI to 150 GeV with >90% efficiency, using 53 Mhz.
- Develop 2.5 MHz acceleration in MI through transition to eliminate coalescing of beam at 150 GeV.

At start this has to break even with Accumulator stacking and show potential of improvement

- If the stacking rate in the Accumulator improves to 15e10 pbar/hour.
- Similar or better emittance of the beam to Tevatron.

Simulated Recycler Stacking

- This calculation assumes slightly improved Recycler performance in stacking efficiency of 85% and present intensity dependent lifetime.
- It is compared with a calculation where lifetime of 100 hours independent of intensity.



- 1e11 pbar/hour
- Transfer every 3 hours
- Recycler shot setup 30 mins.
- 1.6e12 in 25 hours, similar to Accumulator

Summary

- Over the last year we have made significant progress in the Recycler performance.
  - Recycler circulating antiproton beam efficiency >95% and stacking efficiency of about 75% has been achieved.
  - Antiproton lifetime >100 hours for >75e10 pbar.
- We still have several issues related to RF manipulations at stacking and extraction.
- We need several instrumentation upgrade to understand the Recycler better.
- Recycler is very close to being a machine which can be integrated into the complex.
- The proposed Recycler upgrade will make the Recycler fully operational.